MAGNETORESISTIVE ANGLE SENSOR HAVING SEVERAL SENSING ELEMENTS

The invention relates to a magnetoresistive sensor, comprising a main sensing element with a main reference magnetization axis, for determining an angle between the main reference magnetization axis and a magnetic field direction.

The invention further relates to a method of manufacturing a magnetoresistive sensor, comprising a main sensing element, including a main reference magnetization axis, for determining an angle between the main reference magnetization axis and a magnetic field direction.

Such a magnetoresistive sensor and a method of manufacturing are known from the paper Euro sensors XIII, The 13th European Conference on Solid State Transducers, Sep. 12–15, 1999, The Hague, The Netherlands, pages 589–596; "Robust giant magnetoresistance sensors", K.-M. H. Lenssen et al.

Magnetoresistance is the phenomenon whereby the resistance of certain materials changes when a magnetic field is placed on these materials. Ferromagnetic magnetoresistance angle sensors are widely used in non-contact angular position sensors in harsh environments like in automobiles or industry. In general these sensors are insensitive to wear and contamination. When operated in a sufficiently strong, saturating magnetic field, their susceptibility for variations in the field strength is low, with respect either to stray fields such as the earth's magnetic field or other magnetic fields. This makes this kind of angle sensors very tolerant against variations in the distance between the magnetoresistance sensor itself and a bias magnet that generates the magnetic field.

Different kinds of ferromagnetic magnetoresistive sensors are known: anisotropic magnetoresistance (AMR) sensors, giant magnetoresistance (GMR) sensors and tunneling magnetoresistance (TMR) sensors.

AMR occurs in ferrous materials. It is a change in resistance when a magnetic field is applied which is not parallel to a current flow in a thin strip of a ferrous material. The resistance has a maximum value when the magnetic field applied is perpendicular to the current flow.

AMR sensors are typically made of single layer thin films of Ni—Fe structured like a meander. The resistance of these sensors depends on the angle Θ between a current through the strips of the meander and the magnetization direction of Ni—Fe according to $R(\Theta)=R(0°)+\Delta R(1-\cos 2\Theta)/2$.

GMR and TMR sensors are both multilayer configurations with at least two layers. In spin valve GMR and TMR angle sensors one of the two layers is either pinned by exchange biasing to an anti-ferromagnet (AF) layer, of e.g. Ir—Mn, Fe—Mn, or NiO, or consists of an artificial anti-ferromagnet (AAF) formed by for instance CoFe/Ru/CoFe exchange biased by an AF layer. The direction of the magnetization of the said magnetic layer defines the main reference magnetization axis. The other layer (the free layer) is made as soft as possible to follow an external magnetic field direction.

In GMR or TMR sensors the resistance depends on the angle Θ between the magnetization direction of the pinned magnetic layer, which direction defines the main reference magnetization axis, and the magnetization direction of the soft magnetic layer according to $R(\Theta)=R(0°)+\Delta R(1-\cos\Theta)/2$.

The magnetoresistive sensors known from said paper are very suitable for analog angle sensing because of their intrinsic angle dependence.

A disadvantage of the known magnetoresistive sensor is that at relatively low magnetic fields, the output signal deviates from the ideal sinusoidal output signal. The distortion in the sinusoidal output signal occurs in both AMR sensors and GMR sensors and is to a large extent due to the anisotropy of the soft magnetic material, e.g. Ni—Fe, as will be explained hereafter.

In AMR sensors the magnetization direction is determined by a balance between the uniaxial anisotropy of the Ni—Fe material of the strips and the external magnetic field. The uniaxial anisotropy induced during deposition is usually a combination of crystal anisotropy induced during deposition and shape anisotropy. Without an external magnetic field being applied, the magnetization direction is in either one of the two directions along the easy axis set by the anisotropy. In a strong, saturating magnetic field the magnetization direction approaches the direction of the applied magnetic field. A sinusoidal resistance variation is obtained in rotating magnetic fields. At relatively low fields, the magnetization direction deviates considerably from the direction of the applied field which induces distortion in the periodic output signal of an angle sensor based on AMR. Low operation fields, however, are of interest because cheap ferroxdure bias magnets can be used to generate these fields. AMR sensors only offer high angular accuracy in strong fields of about 100 kA/m or larger, which can only be generated by expensive SmCo or NdFeB magnets.

In spin valve GMR and TMR angle sensors the soft magnetic layer usually has a finite anisotropy and is coupled to the pinned layer by orange-peel coupling and magnetostatic coupling. A minimum magnetic field strength is required to overcome the coupling and anisotropy in order to impose the external field direction to the magnetization direction of the free layer. Strong fields, however, also affect the magnetization direction of the pinned layer or of the AAF, which serves as a reference direction for the GMR or TMR element. In practice, it is impossible to fully saturate the free layer, without affecting the magnetization direction of the pinned layer or AAF in all field directions. This limits the accuracy that can be obtained in GMR based angular position sensors.

It is an object of the present invention to provide a magnetoresistive sensor of the kind mentioned in the opening paragraph which sensor is easy to realize and is able to sense the angular direction of a magnetic field accurately in a wide range of magnetic field strengths.

According to the invention, this object is achieved in that the main sensing element is electrically connected to a first correction sensing element with a first reference magnetization axis and a second correction sensing element with a second reference magnetization axis, the first and the second reference magnetization axes making correction angles Θ between 5° and 85° of opposite sign with the main reference axis. During use, the sinusoidal output signal of the main sensor includes a distortion which is to a large extent due to the anisotropy in the soft magnetic material, of for instance Ni—Fe. Especially at low magnetic fields, the magnetization does not exactly follow the external magnetic field direction. The error in the output from the main sensor is corrected by adding two correction-sensing elements. The reference magnetization directions of the first and second sensing elements are arranged at a correction angle with respect to the main reference magnetization direction of the main sensing element, for instance at a positive and negative angle thereto on the respective side of the main sensing element. For an AMR sensing element preferably the bias current of each correcting element is placed at an angle compared to the bias